Pathways and time scales of ocean heat uptake and redistribution in a global ocean-ice model

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How are tracers ventilated into the ocean's interior?

**Time:**
- When tracer injected (summer to summer) \( \text{dye} = 1 \)
- When tracer ventilated (reaches surface) \( \text{dye} = 0 \)

**Space:**
- 29 surface patches (source regions) defined from climatological density following Khatiwala et al. (2009, 2012)

Method: ocean-ice simulations where a dye tracer is injected for one year in each surface patch.
Experimental setup: model and simulations

Ocean-ice model (NEMO+CICE)
Atmospheric forcing: JRA-55
Resolution: 1° horizontal, 75 vertical levels
300-year spin-up, following OMIP protocol

Two main sets of simulations:

- **60-year run** with JRA-55 forcing
  (i.e. 1958-2017)
  Interannual variability – see example 1

- **218-year run** with repeated forcing
  (i.e. “year 1800” to 2017)
  Long time scales – see example 2

All: dye tracers released from 29 patches
Example 1: interannual variability in high latitude ventilation

Strong interannual variability (compares favourably with observations) as expected from MLD’s strong response to surface forcing (air-sea fluxes) in these regions (year 1 ~ MLD variability)

But after year 1, a reduction in MLD (convection) during the following cooling season allows more subduction of water from the previous year in year 2 (and subsequent years?)

There are some exceptions – interplay between convection in Labrador vs Irminger Sea?
Example 2: Atlantic vs Pacific variability on long(er) time scales

Here the dye is summed along full N-S mid-basin cross sections in the Atlantic and Pacific: summing the dye mimics the distribution of a passive tracer that cumulates over time.

Dye along mid-Atlantic cross section (summed between 40ºN-40ºS only)

Dye along mid-Pacific cross section (summed between 40ºN-40ºS only)

Dye summed up over time, depth and longitude

Dye summed up over time, latitude and longitude

Most of dye between 40ºN-40ºS

Core of North Atlantic Deep Water

Dye starts accumulating at depth

Here the dye is summed along full N-S mid-basin cross sections in the Atlantic and Pacific: summing the dye mimics the distribution of a passive tracer that cumulates over time.
Summary and conclusions

Simulations with dye tracers that are “tagged” based on year and region of origin.

Aim: heat as a passive tracer (similarly to carbon, e.g. Khatiwala et al., 2009, 2012)

Dye is summed to mimic the distribution of a passive tracer that cumulates over time.

Initial results from two main sets of simulations:

Interannual variability: strong response to atm forcing in Labrador/Irminger Sea and tracer’s subduction strongly depends on convection during following cooling season.

Long timescales: largest amount of dye found in subtropical gyres – slow ventilation.

Atlantic: more dye accumulates between ~1000-2000m (on this time scale) i.e. NADW
Pacific: more dye accumulating in the abyssal ocean below ~4000m (after ~100 years)

Northern Hemisphere: ~ twice as much dye accumulates in the Atlantic than Pacific.
Southern Hemisphere: accumulation is similar in the Atlantic and Pacific.

Next: more direct interpretation/application to ocean heat uptake and redistribution. But results/analysis are applicable to any passive tracer in the ocean.
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